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ADEQUATE UTILIZATION OF GPS RESOURCES TO PROMOTE THE  
DEVELOPMENT OF CHINA'S AVIATION INDUSTRY

by

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19960409 053

NAIC- ID(RS)T-0059-96

**HUMAN TRANSLATION**

NAIC-ID(RS)T-0059-96 25 March 1996

MICROFICHE NR: 94C000272

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English pages: 26

Source: Cama, China Astronautics and Missilery Abstracts,  
Vol. 2, Nr. 3, 1995; pp. I.-II. 1-14

Country of origin: China

Translated by: SCITRAN

F33657-84-D-0165

Requester: NAIC/TASS/Scott D. Fearheller

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WPAFB, OHIO

NAIC- ID(RS)T-0059-96

Date 25 March 1996

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ADEQUATE UTILIZATION OF GPS RESOURCES TO PROMOTE THE  
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ABSTRACT

After going through numberless calamities, setbacks, and losses from delays, the GPS (global positioning system) project, which lasted 20 years, finally announced the completion of deployment of the GPS satellite constellation which includes 24 satellites, following the sending of the last GPS satellite into orbit by the U.S. in the middle ten days of April 1993.

GPS is one of the biggest developments in the field of aviation and space navigation/monitoring technology since the introduction of radio navigation 50 years ago. The impact of GPS on aviation is particularly profound. The reason is that, due to its success, it allows us, for the first time in history, to achieve a basic system which is capable of guiding all flight phases. 1993 was the first year that the GPS aviation market (including aircraft and airfields) really took off. The reason was that the whole satellite constellation had gone into operation, creating the conditions for aviation applications associated with high precision and global coverage.

In recent years, internationally, global navigation satellite system (GNSS), using GPS as a foundation, as well as future aerial navigation system (FANS), using GNSS as a foundation, have come forward one after the other. Both of these are important applications of GPS in aviation. Obviously, the appearance of new technology will bring important benefits for aviation circles. However, it also presents new challenges. In order to evaluate these very promising new technologies using a realistic attitude, let us begin from investigating GPS development directions and application prospects, combining China's national situation, to seek out the work which we should do and are capable of doing, in expectation of making better use of GPS in order to promote the development of China's aviation industry.

KEY TERMS   GPS navigation   Precision landing   Air traffic control

## 1 The Battle Around GPS Management Jurisdiction

The GPS global positioning system is a strategic project of enormous scale the development of which was done by the U.S. Department of Defense. From the day the execution of the project began, it was in the realm and under the control of the U.S. military. Up to now, a network of 24 satellites has been initially set up. The U.S. Defense Department has already invested 10 billion U.S. dollars. After that, in order to realize monitoring and control, adjustments, and supplementation of the GPS satellite constellation, each year, the U.S. Air Force will still pay at least 500 million U.S. dollars in maintenance costs. As a result, there are dual considerations in military terms and economic terms. Within the U.S. domestically as well as between the U.S. and other nations, disputes associated with management jurisdiction surrounding GPS applications become clearer and sharper by the day.

### (1) Control Questions

Due to the fact that GPS was primarily designed for military missions, the Clinton government hopes--with a presupposition of guaranteeing conformity to the requirements of national security--to strive to reach a maximum number of civilian users. In conjunction with this, it is claimed that this is one type of development which Clinton wants to see. However, the U.S. military has believed all along that its exercising of control with regard to GPS is a problem of legality, stressing that "even into the next century, the Defense Department will still be the manager of GPS". The military is concerned that, due to the fact that, in military activities, the possibility of opting for the use of satellites is in the midst of becoming more and more /2 obvious, "the U.S. must limit the military departments of other nations opting for the use of space based spy satellites and navigation networks". For this reason, the U.S. firmly maintains the implementation of two types of accuracy levels with regard to GPS users (that is, the P code, which pertains to precision positioning, and the standard positioning C/A code) for service. In conjunction with this, in September 1992, together with the Department of Transportation, GPS operating capabilities were redefined in order to facilitate the adding of distinctions with regard to military and civilian users.

Most recently, when the U.S. Defense Department discovered that, in the markets of the Middle East, a type of GPS receiver was being sold which had a price of only 729 U.S. dollars, it was decided to draw up further plans for a series of classifications in order to strengthen control with regard to the export of GPS receivers. It is said that preparations are also being made to dispatch military monitoring personnel to plants that produce receiver antennas.

In order to put an end to this long and drawn out controversy surrounding GPS control jurisdiction, the U.S. Department of Transportation and Department of Defense put to

rest "disputes associated with the operations, technology, and organizational systems with respect to expanding civilian use of GPS". In June 1993, a Defense Department-Transportation Department combined special operating team was set up. Its mission is combined review with regard to the development of GPS applications in order to facilitate making this satellite system, developed by the military, to be capable of being effectively used for the two military and civilian objectives. Review reports are planned to be completed at the end of 1993. However, according to disclosures, in order to decide civilian uses of military technology, and, in conjunction with that, to also guarantee the leadership position of the U.S., from now on, there is a possibility of carrying out investigations with regard to civilians making use of GPS.

#### (2) Jamming Problems

The U.S. military has been concerned right along with the so called "danger of GPS abuse". However, like all similar frontier technologies, the commercial value of GPS is extremely great. The reasons are:

- absolutely military or civilian technology does not exist. Technology is neutral. People can make any technology possess dual capabilities;

- natural laws are universal. They will not change from one country to another. The only possibility of securing the entire contents is in technologies in engineering and manufacturing;

- a number of technologies which are most useful in military matters are equally important when speaking of civilian uses. Technological progress in one field can also be transferred to another field.

For this reason, the problem of strictly controlling the application fields of GPS will become very difficult. The idea the U.S. military has for a method of determination is to opt for the use of a traditional military method of doing things--jamming.

The first method of jamming is simply shutting down GPS satellites--at least, when flying over the air space of local regions where dangers exist. However, following along with the rapid expansion of GPS applications, a global commercial system will be set up in the future. Therefore, this type of method of shutting down is not workable, unless it is possible to obtain global cooperation.

The second type of method is opting for the use of secure P code in military receivers. In navigation satellites which have been launched recently, there is a type of electronic jamming system in all cases in order to make navigation signals distorted. Military receivers which opt for the use of P code possess a type of specialized computer chip. It is capable of making this type of electronic jamming be bypassed. Moreover, in P code receivers, it is also possible to install a type of controllable reception pattern antenna (CRPA). This type of antenna is capable of detecting jamming signals. In conjunction with this, the antenna is made to be not sensitive in the

direction of the jamming, thereby further strengthening its own counter jamming capabilities.

The third type of method is primarily directed toward difference GPS (DGPS) service. U.S. Defense Department officials say, "The U.S. Defense Department has right along paid serious attention to any type of form which is capable of counteracting its efforts--going through the use of "selection availabilities" (SA)--in order to broadcast precision positioning information". The U.S. does not oppose limited scope difference GPS technology. The reason is that DGPS installations--in the unlikely event of war--can be shut off. However, difference calibrations over a wide region mean that any person is capable of making use of appropriate GPS equipment in all cases, guiding their weapons within global ranges. In particular, it very, very greatly increases the homing precision of cruise missiles. If this is the case, P code services then become meaningless. As a result, the U.S. Defense Department is very much on guard against this problem and is in the midst of looking for really practicable ways of limiting DGPS services. However, following along with the development of modern technology, these jammings can be ineffective. For example, users are capable of carrying out the addition of encryption with regard to the radio data links which are responsible for data transmission between ground stations and satellites, and, in conjunction with that, giving them stronger/3 counter jamming characteristics. Even in time of war, it is still very difficult to be discovered and jammed. Since future difference applications are not capable of being checked nor is it possible to realize control on a global basis, it is the same as saying that each military unit in the world is capable of making use of DGPS in every case. Moreover, destroying ground transmitting stations or interference data links cannot prove very effective either. In this regard, the U.S. Air Force is in the midst of newly designing the operating characteristics of the next generation of GPS, hoping to find a way in terms of whole networks to facilitate the ability to execute controls on DGPS once a regional conflict has occurred.

The fourth method is to opt for the use of electronic jamming. The U.S. military has a tentative idea about using electronic methods during future wars to confuse GPS signals so as to make foreign weapons change course, and, in conjunction with that, deviate from their targets. However, enemies, in the same way, are capable of jamming U.S. navigation signals, thereby causing missiles to miss their targets. For this reason, the U.S. is in the midst of developing a specialized technology. Even if enemy jamming device broadcast signals have powers a billion times stronger than GPS signals, GPS receivers are still capable of detecting navigation signals.

### (3) Problems Collecting Fees

The ten billion U.S. dollars that GPS has already consumed apportions out to 50 U.S. dollars for every taxpayer. Moreover, from now on, 500 million U.S. dollar maintenance costs every year will then require that each U.S. citizen must continuously pay



GPS utilization fees beyond their tax burden. For this reason, the outcry domestically in the U.S. to require the government to collect costs from global C/A code users is very great. However, stemming from a variety of causes, the U.S. government has never dared to pledge to do this. On the contrary, on 5 September 1991, the U.S. government--in the International Civil Aviation Organization (ICAO)--announced in a meeting, "The U.S. government will provide to civil aviation limited precision global satellite navigation service beginning in 1993 for at least 10 years. In this 10 year service period, the U.S. government will not collect any additional type of fees from users." In order to dispel user misgivings a step further, it was again announced later, "The U.S. government guarantees to the International Civil Aviation Organization that, if there are any changes in plans, it will be necessary to notify users 6 years beforehand." Up to the present time, the costs of supervising and operating the GPS network are primarily divided between the U.S. Defense Department and Transportation Department.

In summary, with regard to carrying out controls on GPS utilization, it is an established policy of the U.S. military. However, global facilities being controlled in the hands of the U.S. military is a question which is certainly a widespread user concern. This problem will necessarily also give rise to serious attention from China. For this reason, we begin in this article to bring up this question in order to facilitate additional consideration during the development of China's utilization of GPS.

## 2 The Development of Combined GPS/INS Navigation Using Inertia as Its Foundation

GPS is the largest avionics improvement project in the history of the U.S. Air Force. During the 19 years from 1988 to 2006, it is projected that there will be close to 12000 military aircraft fitted or retrofitted with GPS receivers primarily used for navigation purposes. The total investment is close to 1.8 billion U.S. dollars. In the area of civil aircraft, on the basis of Federal Aviation Administration (FAA) estimates, commercial aircraft and general aviation aircraft equipped with and using global satellite navigation systems (GPS or other satellite positioning systems) will be projected as 4000 aircraft by the middle 1990's, as 80000 aircraft by the year 2000, and it will increase to 200000 aircraft by the year 2010. The explanation for this is that GPS used in aircraft navigation will have already become an unstoppable trend. Moreover, the combination of GPS and inertial systems will also account for an especially important place in navigation applications.

In recent years, the mutually complementary nature of GPS and inertial guidance systems (INS) has been repeatedly stressed in various types of international seminars and scientific and technical references. The reason is that, compared to all navigation systems, GPS possesses a compelling advantage in

accuracy. However, the special characteristic of inertial systems being completely autonomous is still one GPS does not possess. Therefore, GPS and inertial guidance combinations have already become an important development trend in aircraft navigation. Table 1 summarizes mutually complementary characteristics of the two. Below, further analysis is carried out of this type of combination.

(1) Advantages of GPS/INS Combined Navigation

GPS is one type of bounded system. So long as receivers are capable of receiving satellite signals, it is then possible to operate. Pseudo range and pseudo range rate data provided are capable of being used in order to calculate position and speed errors associated with combined systems. However, inertial systems are unbounded. The errors increase as a function of navigation times. As a result, it is necessary to add  $\sqrt{4}$  corrections at fixed intervals. Taking GPS position data and using it to act as continuous or selected corrections with regard to inertial system navigation solutions, it is then possible to increase the accuracy of inertial systems. On the basis of viewpoints associated with increases in errors, in this type of combined system, there is then a possibility of permitting option for the use of inertial systems associated with relatively low accuracies.

GPS information and information coming from inertial systems is used to carry out comparisons. After that, making use of their difference values to act as one type of means to standardize inertial components, they are capable of being used to make aerial alignments of inertial systems, thereby permitting combat aircraft to scramble, making high speed reaction into a possibility.

There are basically two forms of inertial system errors--random and repeated. Going through GPS to act as the true position, it is then possible to see how repeatable errors associated with inertial systems change as a function of time and maneuver movements. Once GPS systems are lost, combined systems are capable of reversing themselves to make use of the inertial systems carrying the errors. However, they have already been reduced to where there are only remaining random errors.

As is widely known, inertial systems on fighter planes play various roles--for example, course guidance, providing data for weapons release, flight control, stability sensors, as well as transmission alignment, and so on. Among these, the first two roles are the most important. Due to the fact that any one type of medium accuracy inertial guidance system is capable, in all cases, of providing navigational accuracy which is far, far in excess of what is needed for fighter plane course navigation, as a result, the accuracy requirements with regard to fighter plane inertial guidance systems will primarily be determined by the accuracy of data required for weapons release. These data include horizontal speed, vertical speed, as well as angle of depression and angle of roll.

Assume that, in course navigation, use is made of GPS data to standardize gyroscopes and accelerometers. Moreover, during defensive penetration attack periods--due to the existence of severe jamming and disruption of GPS functions--in maximum 20 min defensive penetration periods, it is thus only possible to rely on inertial systems to operate. In this way, speed precisions associated with the instants of weapon release will be determined from sustainment time periods after the last iteration of corrections from GPS and inertial guidance system error transmission methods.

Table 1 Explanation of Mutually Complementary GPS and INS Characteristics

GPS	INS
-High precision position output (C/A code, 100-157m, three dimensions, root mean square)	-Fair precision position output (0.8n mile/h, circular probability error, typical)
-Bounded position error	-Inertial sensors have drift tendency
-High precision speed output	-Speed output slow to change
-Precision depends on aircraft dynamics	-Precision and aircraft dynamics not related
-Initialization not required. In conjunction, can be used in initial alignment of inertial sensors.	-Requires setting of initial values
-Requires 4 visible satellites (GPS is influenced by such things as multiple path effects and geometrical distribution)	-No requirement for external data (inertial system precision and environment not related)
-Provides precision time data	-No time data provided
-Fuselage acceleration not provided	-Aircraft attitude, attitude change rate, and acceleration provided
-Data replacement rate relatively low	-Data replacement rate high
-Single GPS satellite possesses relatively low integrity	-Single inertial sensor possesses relatively high integrity

Analysis clearly shows that, in order to arrive at target values associated with 8-12mil (mil, circular probability error) weapon release precisions, horizontal velocity accuracies required for modern fighter planes should generally be 0.9-1.2m/s(3-4ft/s)(1 $\sigma$ ) for each axis. As far as velocity errors corresponding to 3ft/s are concerned, position precisions corresponding to defense penetration periods of 10-20min should be 3.4-6.3n mile/h (circular probability error). Position /5 precisions corresponding to 4ft/s speed errors should be 4.5-9.0n

mile/h (circular probability error). The general case is that defense penetration times of 10-20 min, with a flight cross section of first attack/wheel/renewed attack, is more than sufficient. As a result, making use of this time section in order to determine inertial navigation system precision requirements is very conservative. The conclusion of analyses is that, when there is GPS assistance, 4-8n mile/h (circular probability error) inertial navigation system accuracies are sufficient to satisfy the weapon release requirements expected in fighter planes for defense penetration periods of 10-20min.

At present, as far as defense departments with a global scope are concerned, they are all evaluating the potentials which combining GPS receivers and inertial systems together will give aircraft, missiles, ground carrier vehicles, and ships. The reason is that this type of combination will take the inherent high band width and low noise characteristics of INS and combine them perfectly with the low band widths and precision ranging capabilities of GPS receivers.

## (2) Three Types of Coupling Methods

In actual applications, there are three main coupling methods between INS and GPS receivers. They are loose coupling, close coupling, and tight coupling. In loose coupling of GPS and INS, GPS receivers basically function as an autonomous navigational instrument. They are capable--through automatic or manual methods--of supplying periodic position (or possibly speed) corrections. This is one type of typical respectively independent level of combination. The output characteristics will be better, in all cases, than any one independent system. However, it is only capable of utilization under conditions of low fuselage dynamics and low interference (for example, civil aviation aircraft). In environments of high dynamics and high interference, GPS receivers are not capable of simultaneously tracking and querying the 4 satellites needed for a single navigation solution. System precisions will drop down to INS short term precisions.

In a close coupling type of GPS/INS, GPS receivers and inertial guidance systems respectively possess a Kalman wave filter device. They produce navigation (position and speed) data transmitted through an MIL-STD-1553B data trunk line to any central computer. After that, they are then combined there with a third wave filter device. After opting for the use of this type of method, GPS and INS assist each other. However, the precision of navigational solutions depends on carrying out very detailed processing on time synchronous data within these three wave filter devices.

In tight coupling set ups, GPS receivers are made into an EGI (Embedded GPS-INS) system where a piece of circuit board is embedded into INS cases. Independent Kalman wave filter devices are used in order to take the original inertial measurement data (speed increments and attitude increments) and carry out tight coupling with satellite measurement data (pseudo range and pseudo range rate). Due to the fact that what is coupled is measurement

data and not navigational data, it permits wave filter devices to be able to set up error models relatively accurately, thereby making it possible to supply a continuous and accurate navigational solution even if the field of view is smaller than 4 satellites. Its accuracy will also be higher than that obtained using pure inertial systems.

### (3) Embedded GPS Inertial Systems (EGI)

One type of combination navigation system called "embedded GPS inertial system" (EGI) will very quickly achieve wide spread applications in military aircraft. At the beginning of this year, the U.S. Defense Department indicated that the Air Force will act as the lead service for this type of system. The initial applications of EGI are the various F-15A/B/C/D models. The Air Force procurement plan is for a total of around 780 sets within the 5 years after 1993 or 1994. Following that, they will be expanded into other models of combat aircraft (for example, the F-16). The reason is that these aircraft possess similar requirements in a great many areas.

Mutual compensation correlations clearly show that inertial guidance and GPS combinations are one type of ideal navigational design. Moreover, EGI systems where GPS receivers are taken and installed inside INS cases, then, make this type of combination reach optimum performance. The principal reason for the U.S. development of EGI is in order to protect GPS encrypted P code signals. As was discussed before, the U.S. Defense Department prohibits the sending of satellite data corrections to users outside the range of "reception authorized" GPS users in situations where there are SA. In actual implementation, the manifestations are that the U.S. National Security Agency does not permit GPS receivers that can supply P code service to provide precision pseudo ranges and pseudo range rates for calculations on data trunk lines outside their own cases. Even if, during the process of transmissions to the outside, option is made for the use of secure trunk lines, when use is made of hidden variables to lock them up, the whole system is still secure. It is possible to make data security extend to 48 hours duration. Moreover, if one takes GPS receivers and embeds them into INS cases possessing appropriate shielding, then, GPS pseudo ranges and pseudo range rates are then able to carry out direct mixing with inertial data using relatively good time synchronicity, thereby--when there are SA--it is also possible to obtain the full advantages of GPS and INS combination. /6

The second cause is data gap problems. One type of system associated with tight coupling is capable of receiving measurement data coming from any satellite that can be gotten, thereby making GPS data gaps reduce to a minimum. Conversely, what combination designs associated with loose coupling and close coupling rely on is GPS navigation data. When receivers cannot acquire 4 satellites, navigation data will be lost. This is nothing else than saying that carrier dynamics, low altitude flight, or incomplete satellite constellations are all capable of giving rise to large data gaps.



The third reason is counter jamming characteristics problems. Embedded type installations are better able to counter jamming than independent set ups. A test was made making an aircraft flying at an altitude of 150m deal with a target equipped with a 2kW wide frequency band (20MHz) noise jamming device. This aircraft was equipped with independent INS and GPS systems. Moreover, the receivers for which option is made are fixed reception pattern antennas (FRPA). Test results were that it will--roughly within a range of 190km (equal to a M 0.8 flight of 12min)--receive jamming. However, using an embedded type set up and FRPA, these data will respectively drop to be 95km and 6min. When option is made for the use of a type of combination associated with controllable reception pattern antennas (CRPA), system counter jamming characteristics are able to improve further. This is because CRPA antennas are capable of surveying jamming signals. In conjunction with this, antennas are made not sensitive in terms of jamming direction. Moreover, in combined situations, before aircraft emerge from jammer effective ranges, it is possible to use inertial guidance to act as the primary navigational means.

The fourth reason is that inertial guidance systems associated with embedded GPS will be very greatly reduced in volume and weight as compared to independent GPS and INS. Among certain delivery vehicles which stress weight, such as helicopters and missiles, this is an important factor. For example, the H-764G combination system associated with embedded GPS and with the addition of FRPA has a total weight of 9.3kg. However, a type of set up including U.S. Air Force laser gyroscope standard inertial navigation instruments, independent MAGR model GPS receivers, added CRPA, and related antenna electronic circuits weighs 35kg (besides coaxial electric cables, it is capable of making the overall weight greatly increase).

In summary, technology at the present time has already taken this step forward, that is, compact, light weight, and inexpensive GPS receivers have already been turned into ones capable of plugging into systems, and inertial navigation systems are nothing more than one of other systems of this type. Embedded type GPS/INS has hopes in the future of further reducing dimensions, weights, powers, and costs. As a result, one of the keys to continuous miniturization lies in the area of inertial sensors. Besides this, although research associated with combination systems will be primarily used for military purposes, the spin offs, however, can be used in civilian aviation. After U.S. military aircraft, large model administrative jet planes and the majority of civilian jet planes can very possibly opt for the use of syntheses of GPS and inertial reference systems (IRS) or a type of combined IRS/ADS (atmospheric data system)/GPS system--for example, the French A321 civil aviation aircraft just opted for the use of the latter type of design.

#### (4) GPS Attitude Determination

For a long time, all antenna systems took aircraft to be a point target in order to carry out measurements. Moreover, the

aquisition of relatively accurate flight attitude data depended mostly on nonantenna instruments on aircraft. In particular, expensive inertial instruments. However, with the introduction of GPS technology to the world--especially after the appearance of differential carrier wave phase tracking technology in the late 1980's--there was, starting first of all from high level institutes and schools, a surge of research associated with making use of GPS to measure aircraft flight attitude.

The technology associated with using GPS receivers to realize attitude measurements is called GPS interferometry. Its basic principle is the application of interference in antenna waves associated with receiving antennas positioned at two or more locations in order to accurately determine minute displacements associated with base lines connecting these antennas. On aircraft, it is then possible to go through GPS interferometers to supply relative positions associated with antennas at various points on the aircraft. The aircraft attitude is then derived from these positions. The foundation of this measurement is taking GPS measurement positioning accuracies and increasing them to cm or even higher orders of magnitude. It is only in this way that it is then possible to compare angular displacements of lines connecting phase centers of two receiving antennas on the same base line relative to the reference location.

According to the most recent reports, GPS attitude determination has already reached the level where:

- With regard to base lines with lengths that reach 30m, possible precisions are 1mrad(3.4'). If it is possible to actualize precise control of such things as multiple path effects, antenna types, locations, and so on, precisions can then reach 0.1mrad.

- Correction rates are capable of reaching 1kHz.

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- Initialization processes are calculated using s.

Most recent tests at the U.S. Stanford University clearly show that, after GPS is used to precisely determine aircraft attitude, a receiver unit is capable of replacing over 50% of the functions in the current cockpit instruments. During tests, 4 GPS microband even and level antennas are respectively installed on the two wing tips of aircraft, the tip of the fuselage, and the tip of the vertical tail. Normally, antennas can see 5 satellites. Moreover, 4 satellites can be used in order to precisely determine three dimensional positions. However, test measurement data clearly shows that, even if--when the aircraft is maneuvering--there are a few satellites blocked, obtaining a complete attitude solution, however, only requires 2 satellites. During the entire test measurement process, there are always at least 2 satellites placed within the range of the antenna field of view--even during sharp turns and twisting maneuvers. During test flights, option is made for the use of a 3m receiver base line. The results are that attitude precisions are better than 0.1°. Wing warping determinations are 1.4mm. The obtaining of the latter datum is an unexpected aquisition, that is, when using

GPS to do measurements, deformations of aircraft structures placed under stress can be used as an accelerometer because they give precise measurements of wing warping in flight. Tests also clearly show that taking GPS and using it as a course sensor is very attractive because it is not influenced by magnetic variations. Speaking in terms of attitude sensing, GPS also has advantages. The reason is that it will not be damaged because of drift associated with inertial systems or precession associated with spinning gyroscopes.

Research results reported in early 1993 from Germany's Munich University are capable of representing the newest level in this technology. They opted for the use of the newest DGPS/INS techniques and got high precision aircraft navigation system performance which was--position precision 5cm, attitude precision  $0.06^{\circ}$  (0.2'). The basic composition of this type of system is in flight DGPS which opts for the use of carrier wave phase fuzziness solutions and telemetry which opts for the use of new carrier wave phase corrections. Moreover, included among inertial system quick change algorithms there are compensations for circular conical and propeller error as well as aerial alignment capabilities possessed by inertial guidance systems.

It seems that, at the present time, GPS attitude determination technology is just in the midst of the stage of going from laboratory development to engineering tests. Once this technology has achieved a breakthrough, GPS functions will be added to by one. The attitude data makes carrier bodies placed in motion then capable of completing alignment within a few seconds. This is creating conditions for aerial alignment of aircraft inertial navigation systems. GPS attitude determination is the use of a relatively low cost means in order to characterized aircraft attitude. Besides this, it can also furnish to automatic pilot instruments high quality dynamic response data, thereby making it possible to produce even more effective corrections and to provide even more stable flights for passengers. If GPS attitude determination functions are put into practical use, then the superiority of GPS and INS combinations will be manifested even more fully.

#### (5) GPS/INS Combination Guidance Is an Important Direction in the Development of Chinese Military Aircraft

GPS/INS combinations are the biggest requirement in military terms. The reason lies in the fact that this type of combination is capable of very greatly increasing system counter jamming capabilities. In the last 10 years, the course of the development of inertial technology associated with military aircraft is primarily one of taking inertial technology as the basic means and using GPS to act as an external information source to carry out strengthening and improvement with regard to inertial navigation. The U.S. Defense Department, in its most recently announced "Federal Radionavigation Project" (FRP), stipulates that "Positioning/navigation systems associated with systems for military use will be based on GPS, which uses autonomous systems (including inertial, Doppler, and terrain



matching) as its foundation". Even the U.S. military knows its navigation systems should use inertial technology as the foundation. In that case, starting out from China's national situation, the key position of inertial technology in military aircraft should then be stressed even more.

The advantages of GPS/INS combinations are primarily

- increasing counter jamming capabilities of the entire system
- strengthening GPS receiver acquisition capabilities with regard to signals
- ability to lower precision requirements with respect to inertial systems.

This last point possesses real significance with regard to faster development of China's inertial technologies. Going through more than 20 years of effort, China's airborne inertial guidance systems are just in the midst of equipping units step by step. Inertial guidance systems have begun to form one type of fundamental facility associated with China's military aircraft. However, due to such causes as technology, as well as funds, and so on, the level of Chinese airborne inertial guidance systems is very, very far from being able to satisfy mission requirements. However, GPS is one type of ready made aerial data resource. The mutual complementation effects of it and INS have already been discussed above. How to adequately make use of this data source in order to reduce inertial guidance system precision pressures, and, in conjunction with that, promote breakthroughs in key inertial guidance system technologies, is a technological path worthy of exploration. As far as concrete implementation is concerned, it is possible to think of proceeding in accordance with the three stages below.

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((1)) Aggressive Study of Close Coupling Forms of GPS Assisted Inertial Combination Navigation Systems

Introduce from outside China airborne GPS receivers. On the foundation of flexible gyroscope platforms developed autonomously in China, construct GPS receivers and inertial guidance systems that are mutually independent, and, in conjunction with this, close combination systems connected through trunk lines. As far as the systems in question are concerned, pure inertial performance conforms to standard inertial guidance instrument norms. However, reliability is greatly increased, and, in conjunction with that, they possess aerial alignment capabilities, thereby being capable of satisfying relatively well current urgent military aircraft requirements with regard to navigation. The technological key to this type of design is the establishment of models associated with inertial guidance system errors as well as Kalman wave filter device design and realization.

((2)) Strongly Promote Combinations of GPS and Quick Connect Attitude Course Reference Systems (AHRS)

AHRS is a type of low precision inertial system. It is not only capable of supplying aircraft attitude information. It possesses, moreover, crude navigational functions (for example,

navigational precision is 5n mile/h). GPS acts as one type of speed assistance source, capable of making this type of combination system achieve very great improvements in terms of position accuracy, thereby making the entire system reach inertial navigation system performance levels. Moreover, the price is only 1/4 - 1/5 that of the same type of inertial guidance system. Aircraft not equipped with inertial guidance systems (for example, light combat aircraft and the majority of helicopters) could possibly reject the reception of INS/GPS combinations. However, opting for the use of GPS in combination with a type of light, convenient, and inexpensive quick connect course and attitude system is then relatively easy for this type of aircraft to accept.

China's flexible gyroscope technology was an important breakthrough during the period of the "75" plan. The quick connect type navigation and attitude system which was constructed using this was also successful in preliminary development. Therefore, taking it and creating a system with GPS would not be too difficult in technical terms. However, in the retrofitting of Chinese helicopters and light combat aircraft, there will be a very large market. In this way, not only are market demands satisfied, it will also make different standards of inertial systems exert effects in applications at different levels.

### ((3)) Research the Timely Development of Embedded Inertial Systems (EGI)

The status of U.S. EGI development has already been introduced above. In recent years, primarily the European inertial navigation manufacturing companies have also accelerated the creation of this type of system. However, their nations still hold reluctant attitudes at the present time with regard to opting for the use of this type of technology. For example, the French air force has already installed independent GPS receivers on its new dogfighter aircraft. After that, data goes through trunk lines and a communications link is set up with navigation systems. The initial plan of the British Royal Air Force is also to select a type of improved INS and independent GPS receivers, in this way, using the two case loose or close coupling designs. The primary reasons lie in the costs of these combination designs, which will be lower than EGI systems.

Limited by U.S. policy regulations, China is not able to make use of P code receivers. However, we can go through research on EGI systems in order to offset the influences of SA, thereby making the precisions associated with combination systems which opt for the use of C/A code receivers go up, in conjunction with this, very, very greatly reducing cost/benefit ratios. We can draw lessons from such nations as the U.K. and France, beginning the development of EGI research on the foundation of experience with combinations which has already been obtained. We are capable of procuring GPS sensors from outside of China to

manufacture embed type GPS receivers. In conjunction with this, use is made of development results for Chinese laser gyroscopes and optical fiber gyroscopes to create EGI--in order to satisfy the requirements associated with a new generation of combat aircraft.

### 3 Newest World Technologies Associated with Tracking GPS Field Approach and Landing

In recent years, civil aviation circles and industrial circles have studied a good number of techniques to strengthen problems surrounding GPS use in precision field approach and landing flights. Among these, difference GPS (DGPS) technology is only one type of concept for GPS use in increasing the assurance of field approaches and landings. At the present time, it is universally acknowledged that these strengthening techniques already have no problem with the area of making GPS achieve the accuracies required for precision field approaches. The actual problem at the moment is the integrity and continuity of service as well as how to make use of practical methods in order to reach these performances. In view of this, the FAA has already begun a three stage plan in order to speed up progress toward GPS equipment used for precision field approach navigation.

#### (1) GPS Aviation Application Schedule

In December 1992, the FAA promulgated a technical standard directive TSO C-129 in order to provide a loophole for aviation applications of GPS. The current C-115 standard requires that all GPS systems that satisfy this level should, in all /9 cases, carry out cross monitoring and control with regard to their performance. The method is to opt for the use of traditional navigation systems to act as reference. However, as far as the C-129 regulation is concerned, all systems which satisfy its performance and utilization standards (including GPS equipment) are permitted to function as complementary navigational systems for transoceanic and mainland flight routes and terminals so as to opt for their use. "Complementary" has a loose type of meaning, that is, on the outside chance that malfunctions appear in GPS, aircraft are only required to rely on VOR receivers to act as spares. On the basis of the requirements of TSO C-129--with respect to in flight and terminal utilizations--full dimensional deviation is 5n mile. For use in field approach transitions, it is 1n mile. In final field approach positioning, it is 0.3n mile. At runway entry locations, it is reduced to 0.0576n mile (105m). In comparison to GPS receiver precisions set out in Table 2, it is clearly shown that--opting for the use of strengthening technologies--GPS has the capability to reach precision field approach accuracy requirements associated with C-129.

In order to speed up the turning of GPS into civil aviation uses--on the foundation of the C-129 regulation--the FAA took the standard and divided it into three stages. In conjunction with

this, GPS is permitted to be used, step by step, in all phases of flights--in flight, transoceanic, terminal area, as well as nonprecision field approaches.

On 9 June 1993, the FAA announced a decision with milestone significance, that is, U.S. fliers can make use of GPS navigational signals in all phases of flight to act as a complementary navigational means. The first phase of the three phase plan begins with this. It represents the U.S. taking the first step toward aviation applications of navigation systems based on GPS satellites.

The rough meaning of Phase I is to premit--under instrument flight regulations (IFR)--the primary utilization of GPS to complete nonprecision field approaches as well as flights on mainland and transoceanic routes. However, it is necessary to satisfy the three conditions below.

((1)) On aircraft, other already approved navigational systems must be installed--for example, dual inertial systems or dual omega systems. This traditional navigational equipment is a complementary foundation to act as a spare for GPS in order to guarantee the operations.

((2)) As far as GPS field approaches are concerned, it is necessary to superimpose navigation systems based on the ground. That is also nothing else than saying that pilots flying GPS superimposed field approaches must monitor and control already approved non GPS navigation equipment. Ground equipment used in overlapping instrument field approaches are primarily such ones as Fuer (phonetic), Takang (phonetic), nondirectional beacon (NDB), as well as regional navigation, and so on.

Table 2 C/A Code GPS Receiver Positioning Accuracy

① 接收机		⑥ 选择可用性 (SA)	⑦ 局部差分	⑧ 典型精度 (m)
② 码跟踪 (2 通道)	③ 载波相位跟踪 (12 通道)			
	④ 平滑    ⑤ 运动			
✓				20
✓		✓		100
✓		✓	✓	5
	✓			19
	✓	✓		100
	✓	✓	✓	3.5
	✓      ✓	✓	✓	0.2

Key: (1) Receiver (2) Code Following (2 Channel) (3) Carrier Wave Phase Tracking (12 Channel) (4) Smooth (5) Moving (6) Selected Availability (SA) (7) Local Difference (8) Typical Precision

((3)) GPS field approaches must be plugged into avionics equipment data bases. Moreover, field approach course points must be automatically displayed in a continuous sequence.

By the time of the public FAA announcement on 9 June 1993, the FAA had already made use of GPS to carry out 5000 iterations of nonprecision field approaches at 2500 domestic airfields. /10

Phase II is projected to begin in November 1993. At this time, the Department of Defense will announce that GPS has achieved initial operating capability (IOC). As far as the so called IOC is concerned, what is indicated is that, at the appointed time, the complete 24 satellite constellation (21 operating satellites and 3 "hot spare" satellites) will be in operational configuration. Within a 24h global range, it will be possible to obtain adequate GPS signals so as to reach 100m level positioning accuracies (within 95% time periods). If signal availability drops somewhat, the U.S. Defense Department will make a public announcement at least 48h beforehand. As compared to the other type of capability, what is called full operational capability (FOC) is made use of purely to supply military subscribers. It will be brought up later.

In Phase II, if airborne receivers possess "receiver

autonomous integral monitoring and control" (RAIM) capabilities or equivalent GPS integral monitoring and control, then, pilots have no need to monitor other ground based navigational equipment, and option is made for the use of GPS to act as the primary flight guidance in order to make precision instrument field approach. However, at this time, GPS field approach will still be overlapped by a ground based navigation system. We mention this in passing and will refer to it later. The presupposition for the drawing up of standard C-129 is RAIM. This is a complicated software program. All GPS receivers for which option is made in IFR field approach will opt for its built in use. The reason is that it is capable of providing self-diagnostic capabilities in order to guarantee the integrity and precision of GPS satellite transmissions.

With the arrival of Phase III, pilots will opt for the use of GPS receivers already equipped with RAIM. Ground based navigation equipment will be eliminated. As far as GPS field approach is concerned, it will be included in the topic of instrument field approach, that is, it will be permissible to completely use only one means, opting for the use of TSO C-129 equipment to use in navigation and nonprecision field approaches. The time table associated with phase III has still not been precisely determined. However, the last date for procurement to be used in class I instrument landing systems (ILS) is projected as 1995. Moreover, 1995 is the date that the U.S. Defense Department plans to reach GPS satellite constellation FOC. At this time, GPS systems will be capable of replacing one among the other long range navigation systems which have already been approved. Moreover, speaking in regard to certain short range transoceanic flights, which only require one long range navigation means, it is then possible to only opt for the use of single GPS systems carrying RAIM.

What Table 3 presents is a possible development schedule announced by the FAA for precision field approach navigation systems at the 25 March 1993 international "Future of Precision Landing Systems" conference. Table 4 is the implementation process planned by the FAA for GPS applications in aviation as announced in August 1993. In accordance with the schedule at the present time, in 1988, the MLS (microwave landing system) will become the global standard for precision landing. However, the previous generation ILS will still be around for approximately 5 years in order to guarantee a smooth transition. At the present time, there are more and more people supporting opting for the use of navigation based on GPS in order to take the place of the expensive MLS. However--even though GPS is only capable of supplying service levels which approach level I MLS--the objective of the FAA is primarily aimed at taking GPS and raising it to standards equivalent to MIL II level. From Table 4, it can be seen that the year 1993-1994 is the key year for GPS aviation applications. Acting as a type of "complementary" navigation, it will enter into various stages of flights. Moreover, navigation performance is projected to completely attain ICAO requirements



by the middle of 1995.

(2) GPS Strengthening Technologies Under Development

The challenge that the FAA faces is whether or not it is able to opt for the use of GPS to carry out I, II, and III level field approach. However, in recent years, GPS strengthening technologies have achieved great development. As a result, the FAA is full of information with regard to this. Below, there is a simple introduction of a few types of GPS strengthening technologies which have the possibility of speeding up the realization of GPS precision landing.

Table 3 Development Schedule for Precision Field Approach Navigation Systems

1992-1996	Microwave Landing System (MLS) Development
1994	GPS Level I Demonstration
1995	GPS Specialized Level I Operation
1995 (approx)	GPS Level II/III Feasibility Determination
After 1995	Bare Minimum Amount of ILS Installation
1997-2000	255 MLS Ground Stations Set Up
1998	GPS Complementary Level I Operation
1998-2005	Level I Operation with GPS as Sole Means
1998-2005	ILS Begins Elimination
1988	MLS Begins ICAO Transition Period

Table 4 Implementation Process Planned by FAA for GPS Aviation Applications

① 航空阶段	② 1991年	② 1992年	② 1993年	② 1994年	② 1995年	② 1996年	② 1997年	② 1998年	② 1999年	② 2000年	② 2005年
③ 跨洋航路	☆		△		□						
④ 陆地航路	☆		△								
⑤ 终端		☆	△								
⑥ 非精密进场		☆	△								
⑦ I级精密进场				+				△			□
⑧ II/III级精密进场					○						

⑨ 注: ☆——GPS 作为多传感器导航的输入 △——GPS 作为补充导航  
 □——GPS 作为所要求的导航性能的增强 +——用于 I 级的 GPS 增强  
 ○——可行性确定

Key: (1) Aviation Phase (2) Year (3) Transoceanic Routes (4) Land Routes (5) Terminals (6) Nonprecision Field Approach (7) Level I Precision Field Approach (8) Level

II/III Precision Field Approach (9) Note: (star)--GPS acts as multiple sensor navigation input (triangle)--GPS acts as complementary navigation (square)--GPS acts as strengthening for navigation characteristics required + --Used in level I GPS strengthening (circle)--Determination of feasibility /11

((1)) Difference GPS (DGPS)

In the past few years, large amounts of experimentation and flight testing which have been carried out clearly show that DGPS has very great potential in the area of increasing GPS positioning accuracy. Moreover, it is also capable of being used in order to detect and compensate for satellite malfunctions in real time. As a result, it possesses important significance with respect to guiding aircraft to automatic landings.

NAIC-ID(RS)T-0059-96.1 /11

The definition of DGPS is opting for the use of a type of stationary, ground based GPS receiver (GBR) the antenna position of which is determined to reach cm levels of accuracy. It is used in order to precisely determine satellite clock errors, atmospheric errors, and position errors. After that, these correction values are taken and--making use of data links--are transmitted in real time for the airborne receivers (ABR) within its coverage region, making the latter use these data in order to correct their own positioning solutions, achieving the objective of improving their own positioning accuracies.

The characteristics of DGPS are:

- comparisons are carried out of reference measurements with measured positions;
- users opt for the use of corrections (users and references opt for the use of the same satellite);
- common errors are eliminated (offset errors are greatly reduced).

The principal sources of errors associated with DGPS are noise and multiple paths. At the present time, a good number of receivers already have effective wave filter technologies to reduce this type of noise influence. However, multiple paths are still an important obstacle. This is particularly the case in precision navigation applications on the ground or approaching the ground. However, in international terms, a type of optimal DGPS receiver structure which was most recently put forward--multiple path determination delay locked circuits--has a possibility of making this problem reduce to controllable levels.

The concept of macrozonal difference has also gotten study in recent years--for example, the Inmarsat-3 satellite was prepared to broadcast difference corrections for civilian GPS users. The first Inmarsat-3 satellite is projected for launch into geosynchronous orbit at the beginning of 1995. It can be used in order to broadcast the same kind of GPS signals. The



functions which this type of signal can provide are:

- measuring the pseudo range to this satellite to use in calculating user position;

- supplying net integrity data on the basis of which to identify any GPS satellite the signals of which are already in excessive error;

- obtaining from ground monitoring and control stations a macrozonal difference correction. Vertical accuracies can reach 6-7m.

The U.S. Defense Department does not oppose local range DGPS. The FAA is just in the midst of planning to install it in the vicinity of airfields. However, the Defense Department /12 is concerned that macrozonal difference corrections coming from an Inmarsat-3 satellite are capable of very, very greatly increasing enemy cruise missile homing accuracy. For this reason, a controversy has also been provoked between users and the Defense Department.

Most recently, engineering circles have paid very great attention to the problem of potential for easy damage with regard to DGPS. The reason is that, when under threat, the consequences for DGPS are much more severe compared to GPS or VOR/DME, and so on. In particular, internationally, there is a universal suspicion that the U.S. is not capable of guaranteeing the Defense Department's giving up control with respect to its GPS network. As a result, a number of European civil aviation officials have brought up the necessity of forcing the U.S. to agree to implement an international treaty that has binding force. Otherwise, aviation applications of GPS--in particular, international aviation applications--will face challenges.

#### ((2)) Carrier Wave Phase Tracking

This technology achieves submeter level positioning accuracies through tracking each carrier wave or phase radiated by GPS satellites. Its simple principle is that one aircraft receives position data coming from several satellites and a ground station. However, airborne GPS receivers are capable of taking this aircraft's positions and reducing them down to a few possible types of positions. In conjunction with this, through carrier wave superposition positioning, each possible location is calculated out. When three or more carrier waves exactly superpose, the true position can then be precisely determined.

This type of DGPS, which opts for the use of carrier wave phase tracking, can make vertical positioning accuracies greatly increase. On the basis of the estimates of research personnel, at the end of 1994, vertical precisions will be made to reach 2-4m. In 1995, they will reach less than 1m, thus placing very well within the limits associated with level III landings. That is nothing else than to say that, after strengthening supplied by carrier wave phase tracking is combined with DGPS, there is a great deal of hope that, in the future, landing precisions associated with level II and level III will be achieved.

((3)) Kinetic GPS Landing System (KGLS)

Local range DGPS is capable of supplying adequate precision for level I field approach. However, vertical precisions are forecast as being 3m-5m--not adequate to satisfy relatively low visibility level II and level III landing requirements. These two types of landings respectively require 1.8m and 0.6m precisions. However, KGLS is capable of making DGPS system precisions increase. Altitude errors associated with test flights do not reach 0.3m.

KGLS is capable of increasing positioning precisions a step further. The reason is that it opts for the use of carrier wave phase tracking technology. Making use of this type of carrier wave modulated code signal, it is possible to use them in order to calculate "whole number period fuzziness" problems. The motions of satellites themselves in orbit as well as relative movement between satellites and aircraft make the GPS signals received by GPS receivers on planes produce Doppler frequency shifts. The cause of this is the formation of whole number period fuzziness, thus influencing positioning accuracy.

In March 1993 at the second annual difference satellite navigation meeting, the U.S. Stanford University put forward the concept of what was called the "Stanford bubble", which is nothing else than this kind of system. It opts for the use of two ground pseudo satellite transmitting stations and one ground reference station. The former send out false GPS satellite signals. The latter simultaneously receives true GPS signals (with frequency deviation) and false GPS signals (without frequency deviation). After correlation, they are sent out again to aircraft approaching fields. Due to the position of the ground station itself being already precisely known, as a result, it is possible to help on board GPS systems increase positioning accuracies. Low power (a few mW) is the key to this concept. When aircraft are positioned close by, low power transmission eliminates the problem of GPS satellite transmissions possibly being cut down by false satellite transmissions. Besides this, low power also produces clear regional characteristics. It is only when signals are within the region in question that it is then possible to receive them.

((4)) GPS Relative Guidance Systems

Despite the fact that difference GPS has already become the satellite based precision landing navigation method which attracts the most attention, the relative navigation, however, which industrial circles most recently put forward is also capable of achieving DGPS navigation results. The foundation of relative navigation is that, knowing the relative positions of GPS receivers on an aircraft and receivers of a target airfield on the ground is more precise than knowing the absolute positions of each receiver.

During actual applications, aircraft approaching fields must receive GPS satellite signals to precisely determine their own absolute position. Signals sent out by airfield beacons are

received to precisely determine the relative positions of aircraft and airfield. After comparing the two, it is then possible to calculate out vectors of aircraft relative to landing points.

One of the advantages of relative navigation is that there is no need to measure the positions of GPS receivers associated with airfields or signal beacon positions. This is capable of saving a good deal of expense and calculation time. Aircraft field approach capabilities with regard to airfields with the lowest security, low traffic capacity airfields, or temporary/13 commercial airfields. As a result, it is possible for it to be attractive with respect to certain commercial applications. The drawbacks of relative navigation are that aircraft and ground beacons must track the same satellite. As a result, there is a need to coordinate consistently.

Simulation tests which have already been completed clearly show that the precisions of relative navigation in all coordinate systems are within 2m in every case. Vertical precisions are 1.7m. Lateral precisions are 0.72m. It is completely possible to satisfy level I field approach requirements for errors within the range of  $\pm 4m$ . Besides this, relative navigation will not be subject to interference from GPS integrity malfunctions.

(3) Maintain Tracking of GPS Landing Technology to Prepare to Link Up with the International Aviation Market

ICAO has already decided to fix 1998 as the cut off date for MLS installation at all international airfields. However, with regard to the prospects for near term GPS use in precision landing, there is still a divergence of viewpoints internationally. The U.S. attitude is already very clear. The FAA hopes to relize the phase I plan next year in regard to 5000 U.S. airfields installing nonprecision field approach equipment. In conjunction with this, it is estimated that, in the end, all 12900 U.S. airfields will make use of GPS field approach. The British attitude is very cautious. At the present time, their airfields are primarily dependent on very high precision classes of MIL. This situation is due to a great deal of bad weather in the U.K. The second reason is that the date for utilization of GPS field approach is not certain. This will be an enormous risk for the U.K. Germany is preparing to accept GPS landing, and is, at the moment, in the midst of stepped up research associated with difference technologies.

China presently has 109 civil aviation airfields. Among these, less than 10 airfields have 2 runways, and, in conjunction with that, are capable of Boeing 747 take offs and landings. 3 of the busiest airfields (Guangzhou's Baiyun Field, Beijing's Capital International Airport, and Shanghai's Hongqiao Airfield) anxiously await construction improvements to the fields. Airfields in the majority of localities have no way to accomodate even more aircraft because of a shortage of runways and backward landing technology. Large numbers of military airfields are even simpler and cruder in their facilities and obsolete in their

technology. GPS precision landing technology is capable of using extremely low costs to supply automatic landing capabilities. As a result, as far as making use of GPS to realize airfield landing automatization and modernization is concerned, this possesses real significance with regard to speeding up the development of China's aviation industry.

The FAA has already recommended to the ICAO that, in the future aviation navigation system (FANS), which is vigorously proposed, future civil aviation navigation missions be undertaken by satellites. The FAA believes that satellite navigation represents one type of opportunity. Through opting for the use of a type of interchangeable receiver, it is possible to make civil aviation operations standardized at any locality on the globe. The FAA also clearly put forward: "The principal single navigation system of the 21st century will be provided by the global navigation satellite system (GNSS). Satellite navigation systems are capable of leading to the discontinuing of current operations by national airspace ground equipment." Although, at the present time, GNSS is still in the early stage of development, it is, however, providing a national standard as well as using economic methods to guarantee that all phases of flight operations obtain high precision positioning information--an area that possesses potential. As a result, this great trend cannot be doubted. China should, as early as possible, begin to get on track with the international civil aviation market. This is not only a task for civil aviation departments. It is also a mission for our industrial and scientific research departments. First of all is the drafting of a unified program for the development of China's application of GPS in civil aviation. In conjunction with this, there should be no break in the line in terms of research associated with GPS precision landing. The General Aviation Industry Company has a foundation of studies, experiments, and test flights associated with GPS landings of more than two years. It is hoped that it will be possible to create conditions for taking this tracking and testing work and carrying it out further. Otherwise, the gap with the international, which is basically not large, will grow bigger. This is very regrettable.

#### 4 Brief Summary

Personages in global aviation circles and industrial circles universally believe that global communications, navigation, and monitoring systems based on satellites will become the key to improvements in global civil aviation industries. In conjunction with this, they will very, very greatly give impetus to the development of military aviation. As a result, Chinese research and development work associated with the development of GPS aviation applications is correct and timely.

To summarize what was described above, considering it from the overall factors, the author believes that, in GPS aviation applications, there is a need to stress:

(1) Seize opportunities to study GPS/INS combination navigational systems using inertial navigation as their foundation. For this reason, speed up the development of Chinese inertial navigation technologies. Promote breakthroughs in key technologies associated with airborne inertial systems, thereby adapting early on to requirements of various types of Chinese military and civilian aircraft with regard to advanced /14 navigational systems.

(2) Organize energies to track and test GPS precision landing flights, seeking out domestic users to provide aircraft for test operations, airfields, and potential markets. The objective is to complete, within the next 3-5 years, the entire process of GPS precision landing refit--test flight--installation on aircraft, in order to facilitate not losing the opportunity to ultimately capture the domestic market.

(3) Pay close attention to the FANS project, carried out by the International Civil Aviation Organization (ICAO), strengthening scholarly exchange activities inside and outside China as well as information tracking and research. Strive to put the development of Chinese civil aviation activities into large international civil aviation programs early on, making China's aviation enterprises really move toward the world.

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